Single Spin Asymmetry Results From Hall-A Neutron Transversity Experiment

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(For Hall-A E06-010 Collaboration)

XIX International Workshop on Deep Inelastic Scattering (2011)
14th April, Newport News, VA, USA

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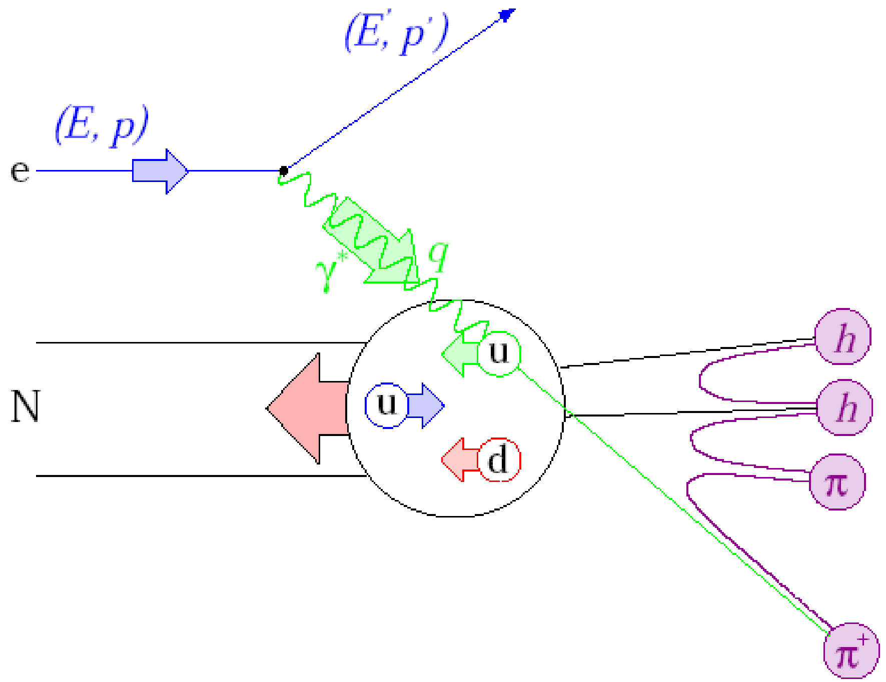
Semi-inclusive DIS

- Detect one hadron in coincidence with the scattered electron
- Flavor tagging is possible through fragmentation function
- $z = E_h/\nu$ at least > 0.2



Semi-inclusive DIS

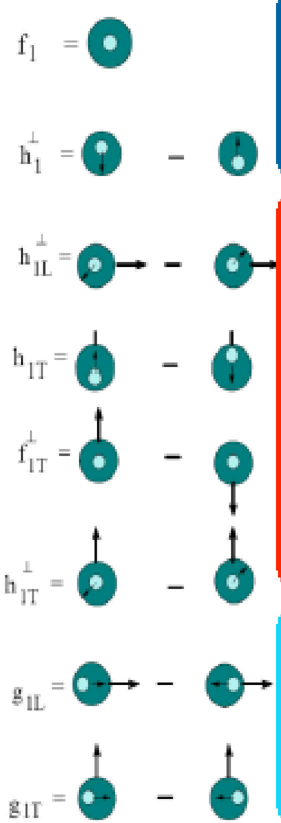
$$\frac{d\sigma}{dx\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)} \cdot$$

Boer-Mulder

Transversity/ Collins

Sivers

Pretzelosity



$$\{F_{UU,T} + \ldots$$
$$+ \varepsilon\cos(2\phi_h)\cdot F_{UU}^{\cos(2\phi_h)} + \ldots$$

Unpolarized

$$+ S_L[\varepsilon\sin(2\phi_h)\cdot F_{UL}^{\sin(2\phi_h)} + \ldots]$$
$$+ S_T[\varepsilon\sin(\phi_h+\phi_S)\cdot F_{UT}^{\sin(\phi_h+\phi_S)}$$
$$+ \sin(\phi_h-\phi_S)\cdot(F_{UL}^{\sin(\phi_h-\phi_S)} + \ldots)$$
$$+ \varepsilon\sin(3\phi_h-\phi_S)\cdot F_{UT}^{\sin(3\phi_h-\phi_S)} + \ldots]$$

Polarized Target

$$+ S_L\lambda_e[\sqrt{1-\varepsilon^2}\cdot F_{LL} + \ldots]$$
$$+ S_T\lambda_e[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\cdot F_{LT}^{\cos(\phi_h-\phi_S)} + \ldots]\}$$

Polarized Beam and Target

S_L, S_T: Target Polarization; λ_e: Beam Polarization

Access to Leading Twist TMDs in SIDIS

		Quark polarization		
		Un-Polarized	Longitudinally Polarized	Transversely Polarized
Nucleon Polarization	U	$f_1 =$		$h_1^{\perp} = \; - $ Boer-Mulder
	L		$g_1 = \; - $ Helicity	$h_{1L}^{\perp} = \; - $
	T	$f_{1T}^{\perp} = \; - $ Sivers	$g_{1T} = \; - $	$h_{1T} = \; - $ Transversity $h_{1T}^{\perp} = \; - $ Pretzelosity

: Probed by E06-010

(Jin Huang's talk)

Nucleon Spin

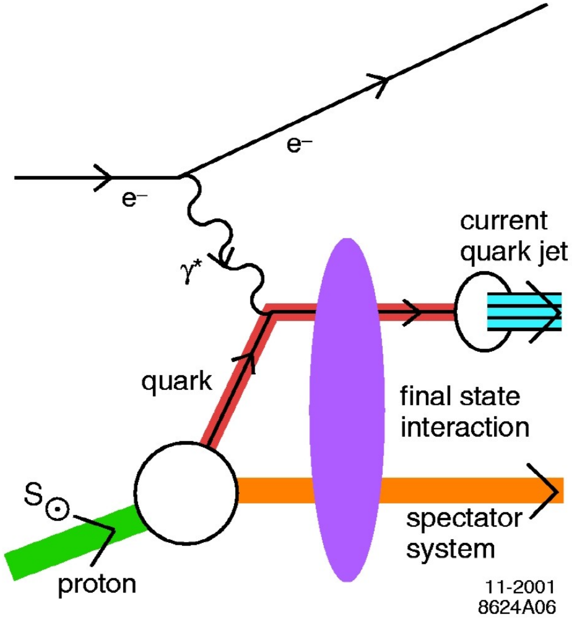
Quark Spin

Collins and Sivers Moments in SIDIS

Collins:

$$A_{UT}^{Collins} \propto \frac{\sum_q e_q^2 h_1^q(x) H_1^{\perp(1)q}(z)}{\sum_q e_q^2 f_1^q(x) D_1^q(z)}$$

- Transversely polarized quark generates left-right asymmetry during fragmentation
- Least known leading twist quark distribution function
- Integral over x_b gives the tensor charge of the nucleon
  - Fundamental quantity, calculable in Lattice QCD



Sivers:

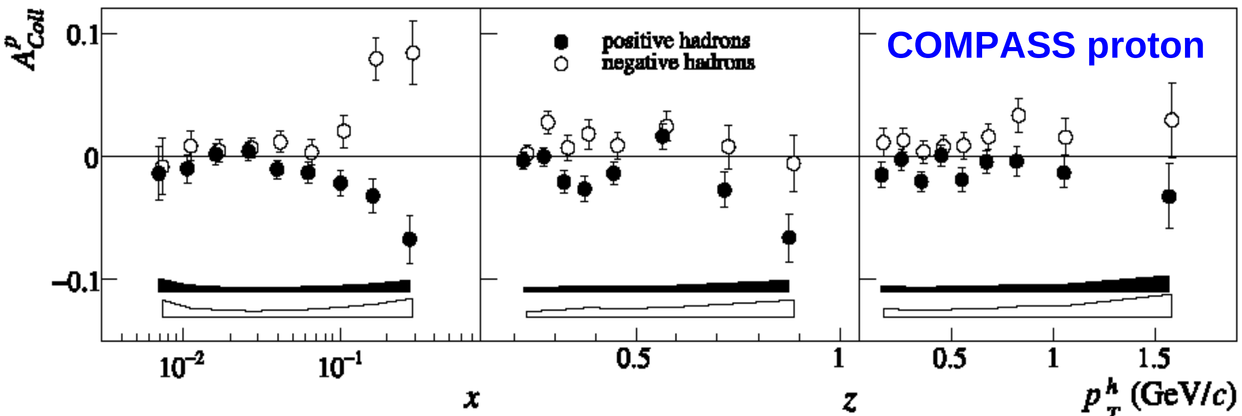
$$A_{UT}^{Sivers} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp(1)q}(x) D_1^q(z)}{\sum_q e_q^2 f_1^q(x) D_1^q(z)}$$

- Left-right asymmetric quark distribution in a transversely polarized nucleon
- Related to the angular momentum of quarks L_q
- Final state internactions (FSI) can lead to non-zero asymmtries (Brodsky, Hwang, Schmidt, 2002)

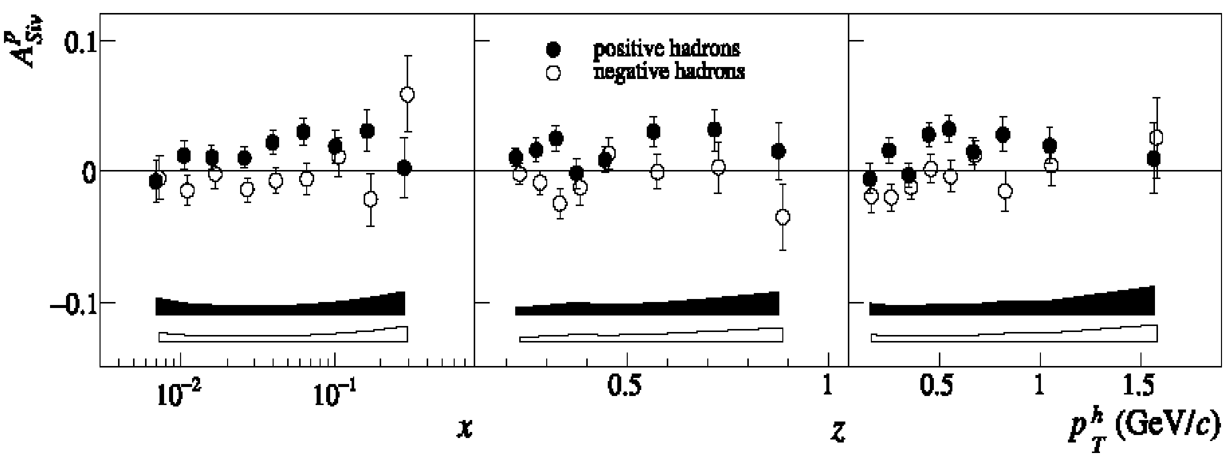
Currently Available SIDIS Data on A_{UT}

- Currently available data in SIDIS :
  - HERMES proton (2002-2005)
  - COMPASS proton (2007) and (2010-11)
  - COMPASS deuteron (2004-2006)
    (deuteron asymmetries are consistent with zero)

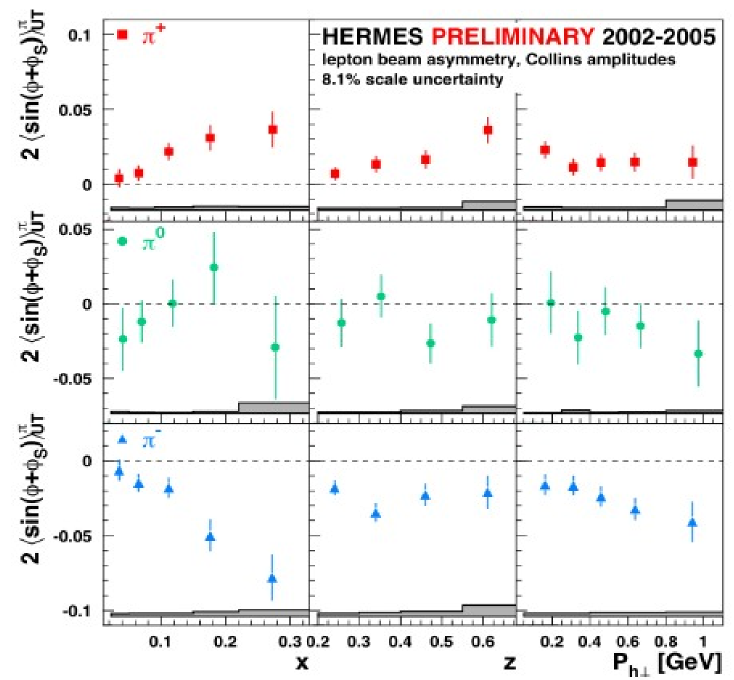
Collins



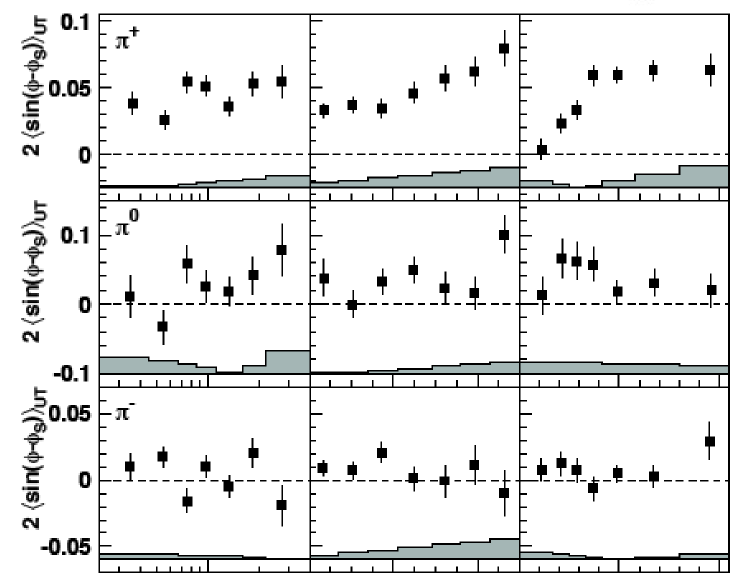
Sivers



Collins



Sivers

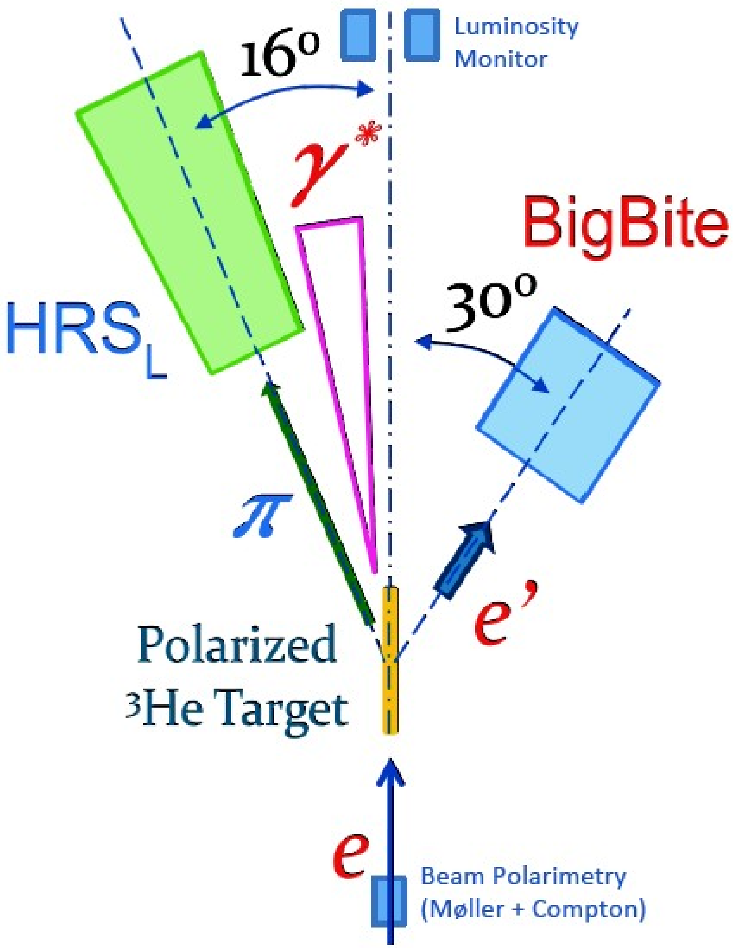


E06-010 Experiment in Hall-A

$^3He^{\uparrow}\ (e,\ e'\ h\ )X$

$h = \pi^{+/-},\ K^{+/-}$

- First measurement of SSA on transversely polarized ^{3}He target
- **Run period**: Oct 2008 – Feb 2009
- 40 cm polarized ^{3}He target cell
- Beam energy : 5.9 GeV
- BigBite at 30^0 as Electron Arm
  - P_e = 0.6 – 2.2 GeV/c
  - Acceptance : 64 msr
- HRS-L at 16^0 as Hadron Arm
  - P_h = 2.35 GeV/c
  - Acceptance : 6msr



Access to Transverse Spin Observables in SIDIS

Separate different effects through azimuthal angular dependence

- **Collins asymmetry:**

$$\sigma_{UT}^{SIDIS} \propto \sin(\phi_h + \phi_S)\ h_1 \otimes H_1^\perp$$

- **Sivers asymmetry:**

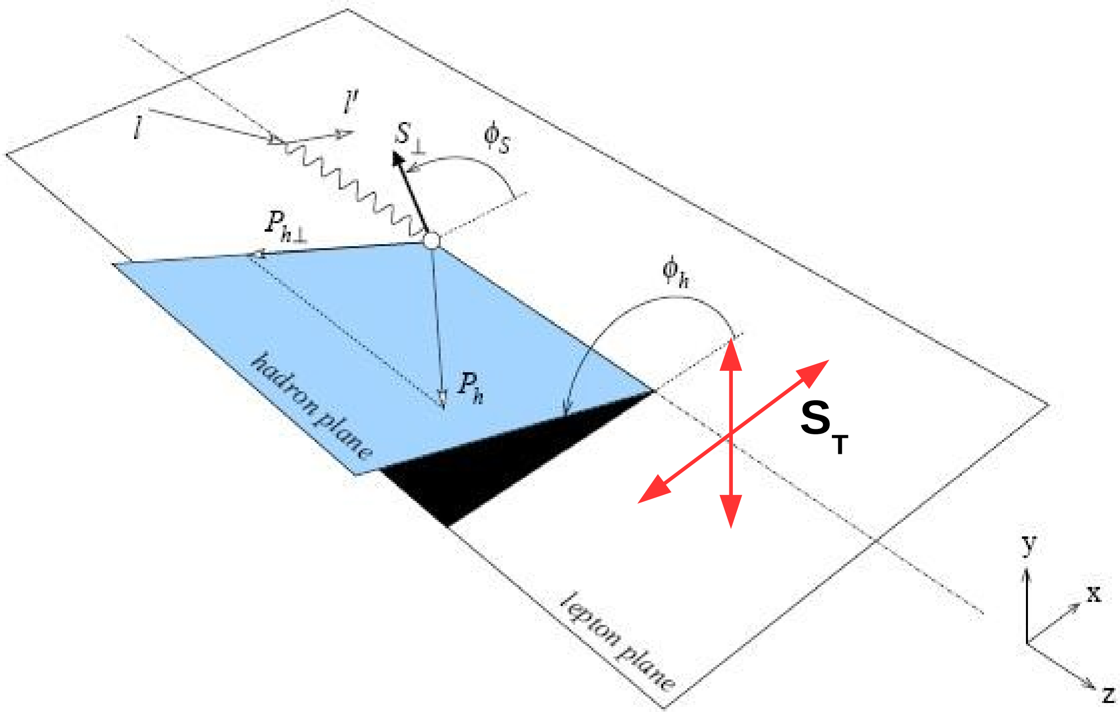
$$\sigma_{UT}^{SIDIS} \propto \sin(\phi_h - \phi_S)\ f_{1T}^\perp \otimes D_1$$

- **“Pretzelosity”:**

$$\sigma_{UT}^{SIDIS} \propto \sin(3\phi_h - \phi_S)\ h_{1T}^\perp \otimes H_1^\perp$$

- **Double-spin asymmetry:**
  (long. polarized beam)

$$\sigma_{LT}^{SIDIS} \propto \cos(\phi_h - \phi_S)\ g_{1T} \otimes D_1$$

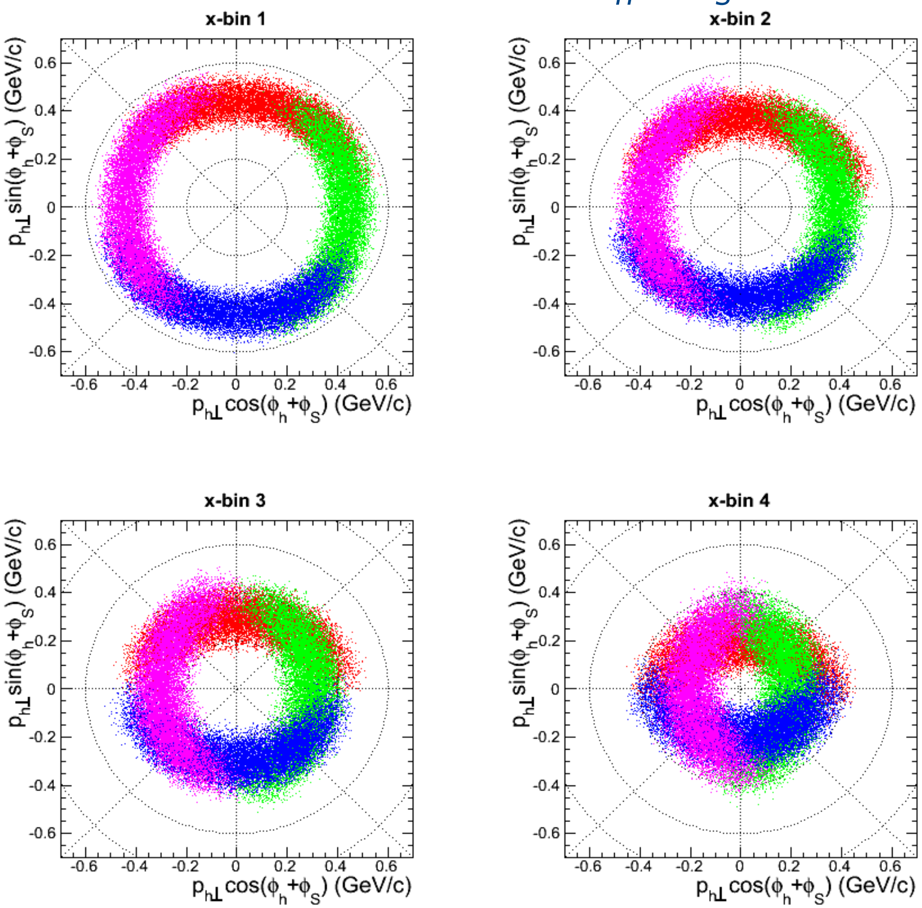


- Target spin orientations: up-down and left-right
  (increases angular coverage)
- Automatic target spin-flip every 20 mins
  (keeps systematics due to target under control)

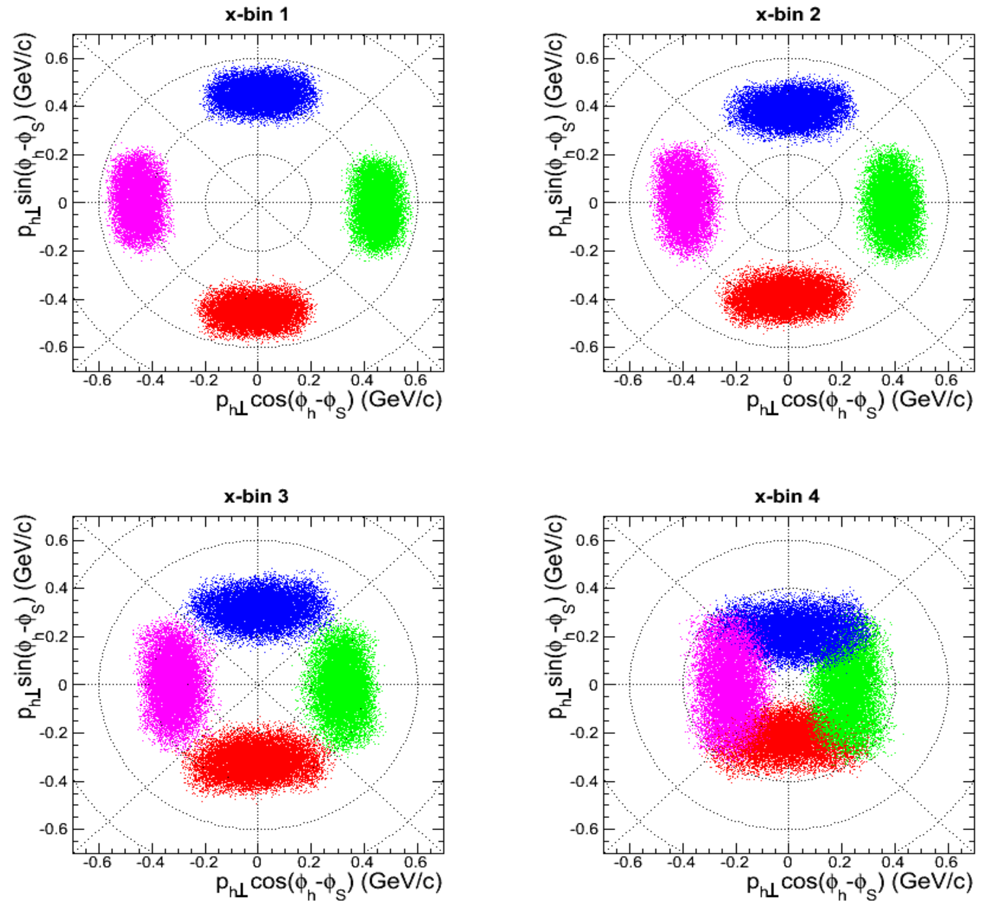
$$A_{UT}(\phi_h, \phi_S) = \frac{1}{P}\ \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$

Angular Coverage

Collins angle: $\phi_h + \phi_s$

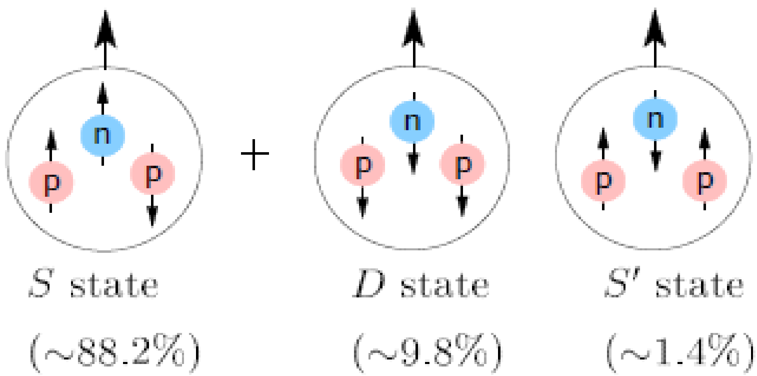


Sivers angle: $\phi_h - \phi_s$

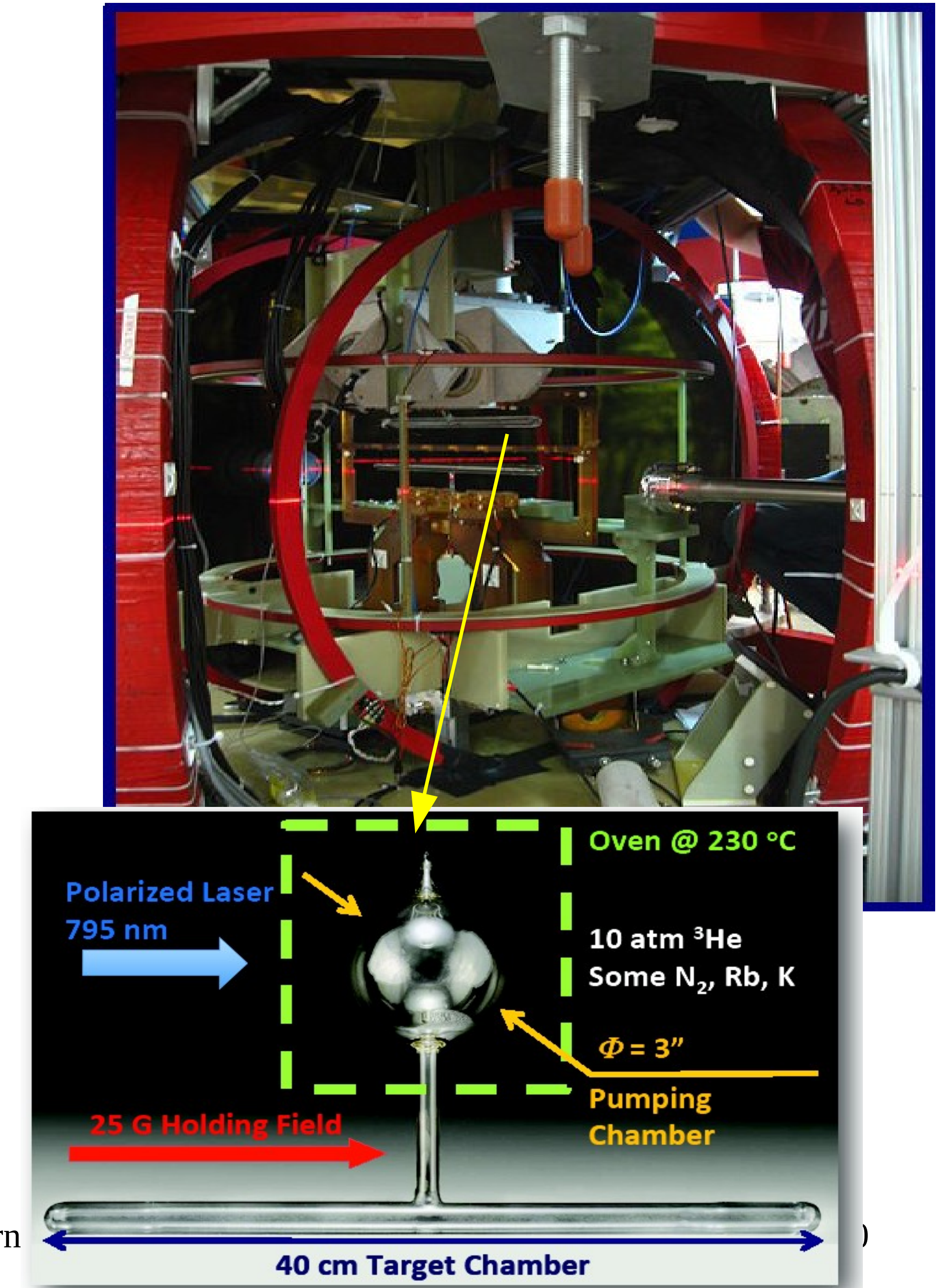


Different colors corresponds to different target spin states - left, right, up and down

Polarized ^{3}He Target

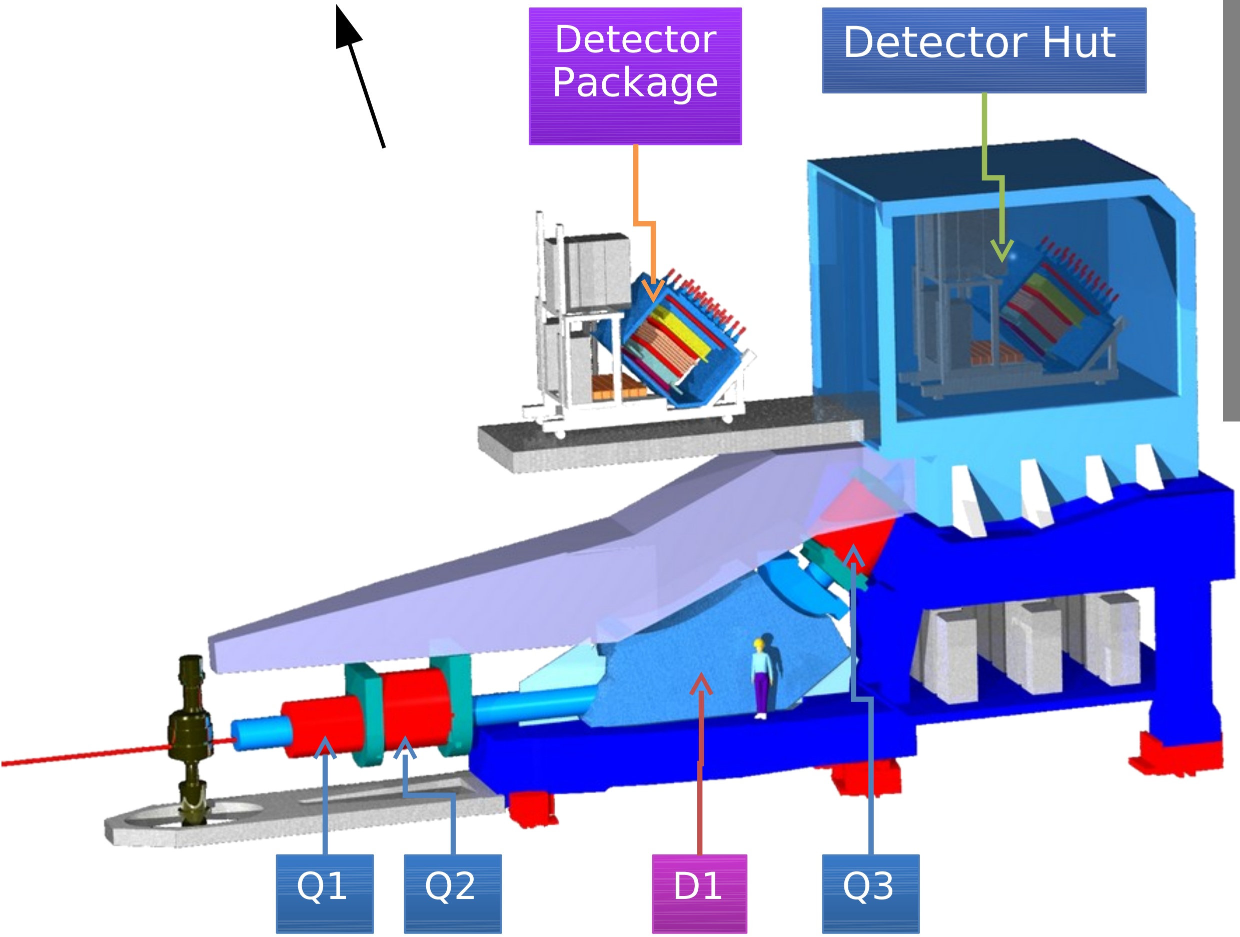


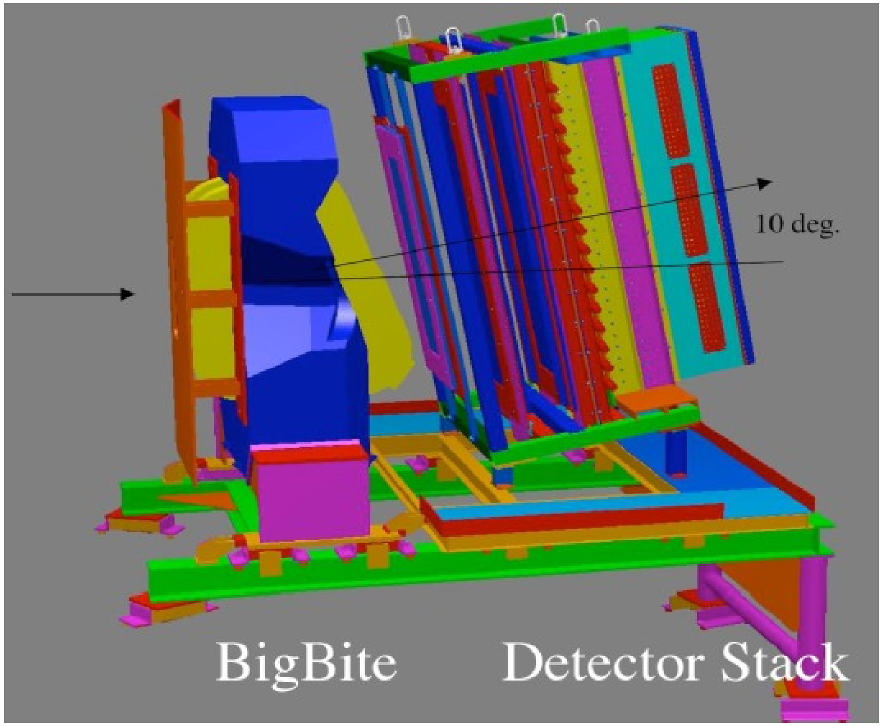
- Effectively a polarized neutron target
- ^{3}He mix with Rb+K hybrid cell, $L(n) = 10^{36}\mathrm{cm}^2/\mathrm{s}$
- Polarimetry using NMR and EPR
- Avg. polarization : ~ 65%



HRS and BigBite Spectrometers

High Resolution Spectrometer
(hadron arm)



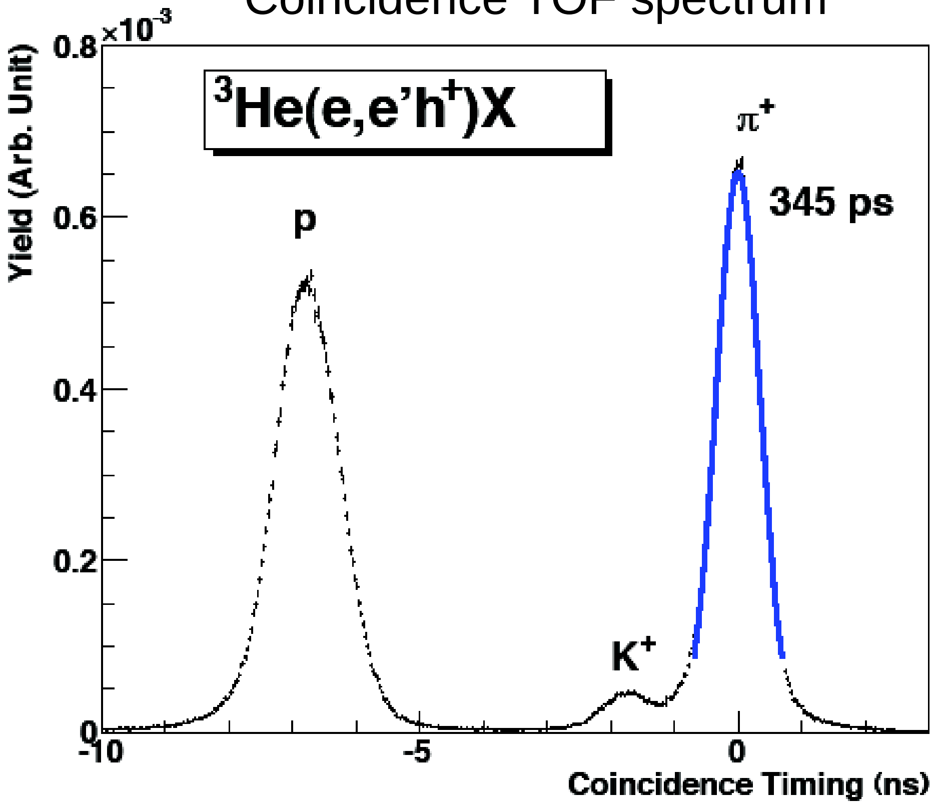


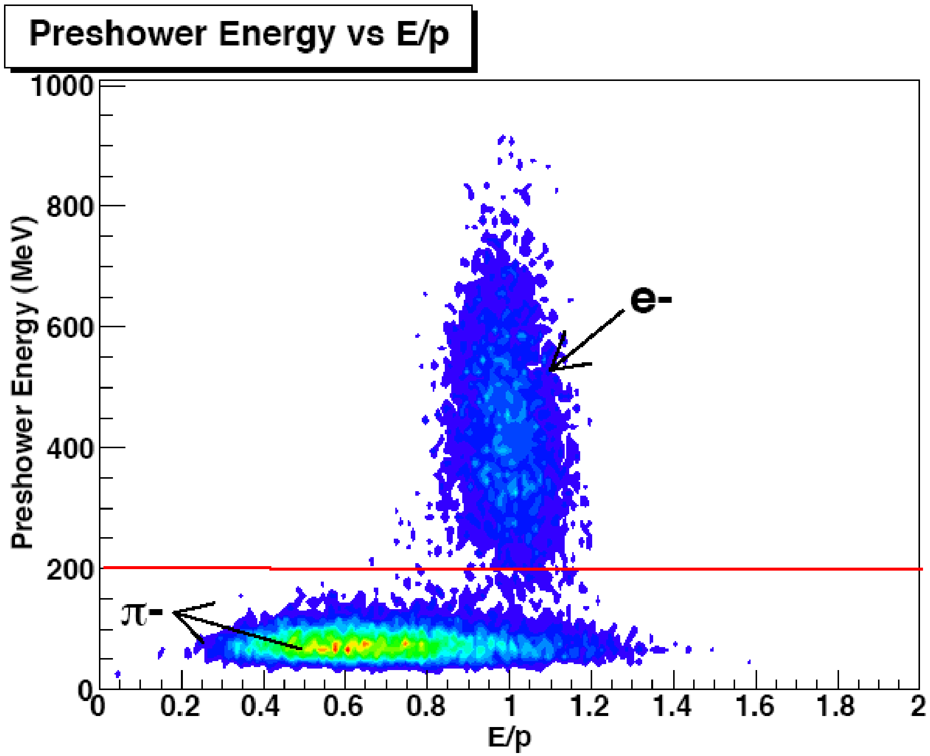
Large Acceptance
BigBite Spectrometer
(electron arm)

Particle Identification

Hadron Identification from HRS

Coincidence TOF spectrum





Electron PID from BigBite

Data Analysis

- Kinematic cuts :
  - $Q^2 > 1.0\ GeV^2$
  - W > 2.3 GeV
  - W' > 1.6 GeV

Asymmetry:

$$A(\phi_h, \phi_S) = \frac{1}{|S_T|} \frac{Y_{\phi_h,\phi_S} - Y_{\phi_h,\phi_{S+\pi}}}{Y_{\phi_h,\phi_S} + Y_{\phi_h,\phi_{S+\pi}}}$$

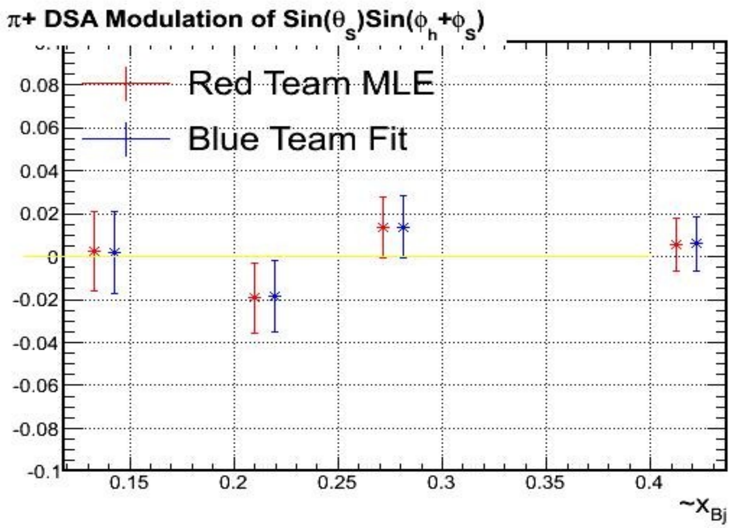
- Normalized yields are formed taking into account: beam charge, DAQ dead time, detector efficiencies, target density etc...
- Two teams did independent analysis using:
  - Angular bin fit method (using asymmetry of local spin pairs)
  - Maximum Likelihood Extraction (MLE) method
- Account for small amount of N_2 in the ^{3}He target cell
  - Nitrogen dilution:

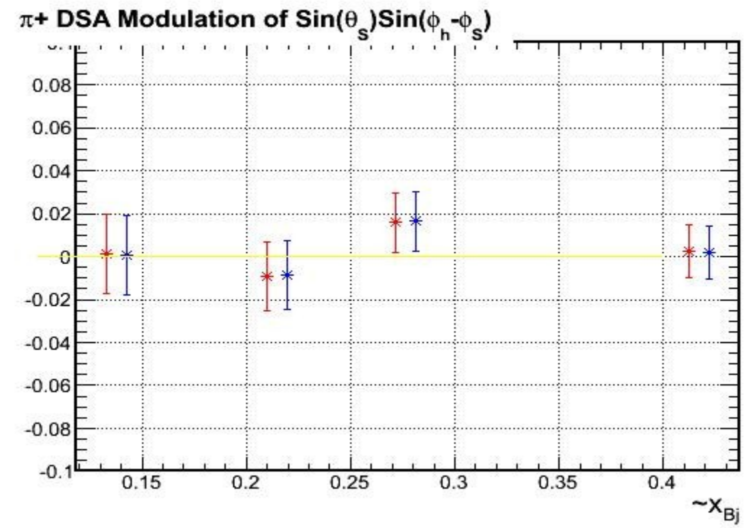
$$A_{raw} = f \cdot P_{^3\mathrm{He}} \cdot A_{^3\mathrm{He}}$$

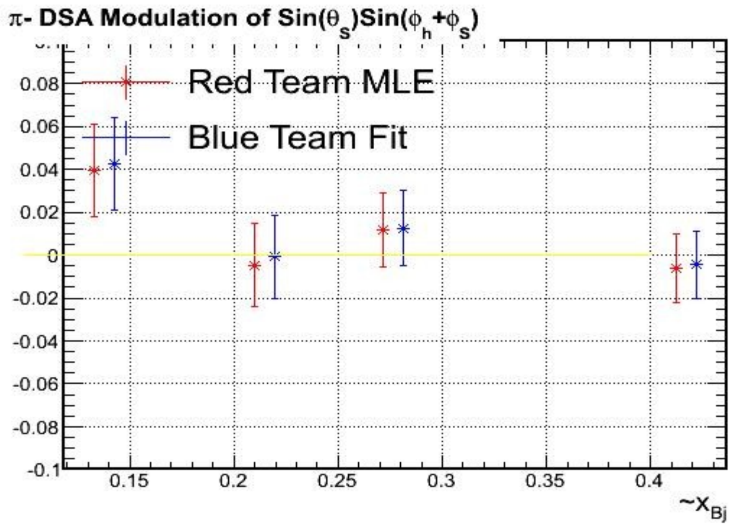
$$f = \frac{N_{^3\mathrm{He}}\sigma_{^3\mathrm{He}}}{N_{^3\mathrm{He}}\sigma_{^3\mathrm{He}} + N_{\mathrm{N}_2}\sigma_{\mathrm{N}_2}}$$

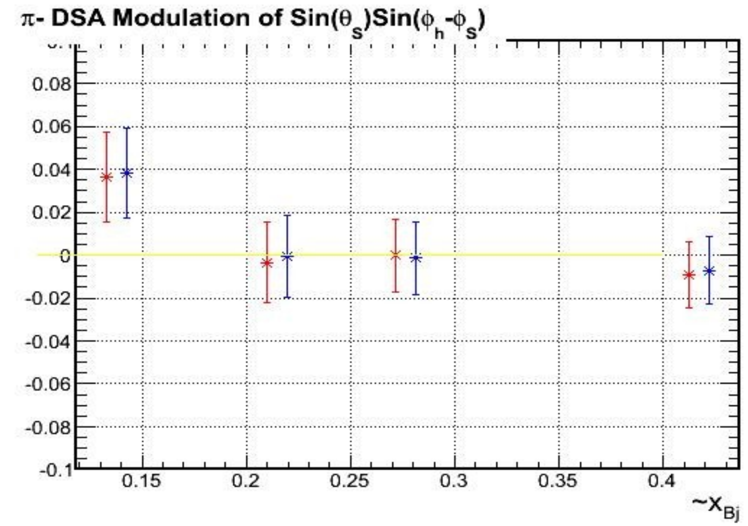
MLE vs Local Spin Pair Method

- Consistency check between two methods



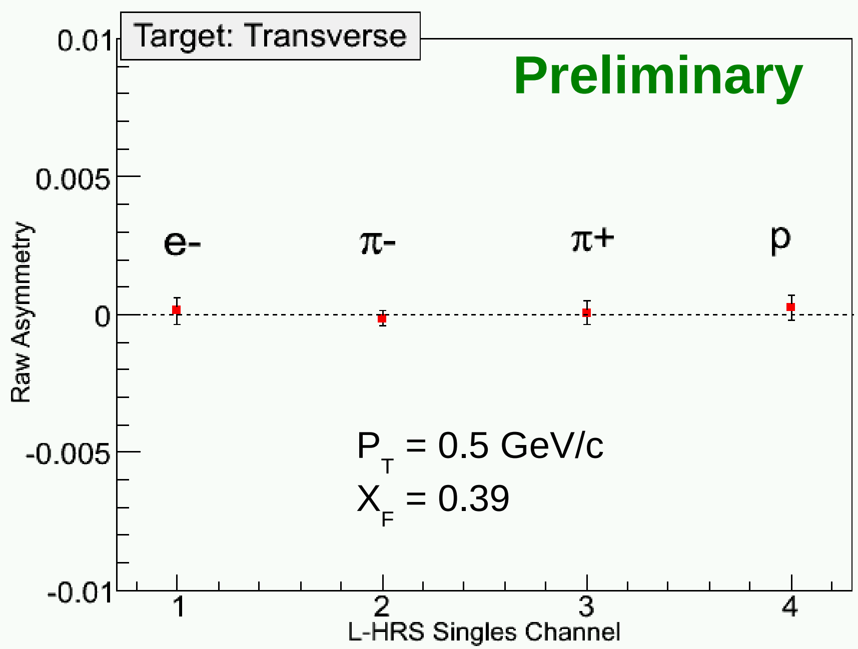


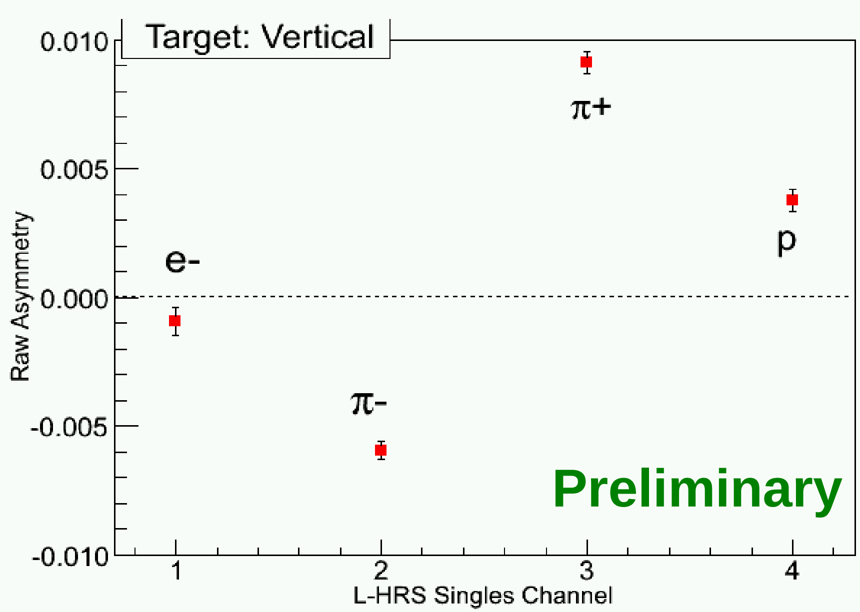




Checks: Inclusive Raw Asymmetry

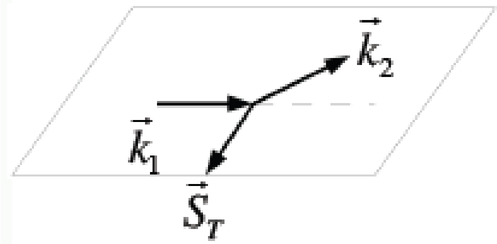
(Witness channels on ^{3}He, not corrected for target polarization and dilution)



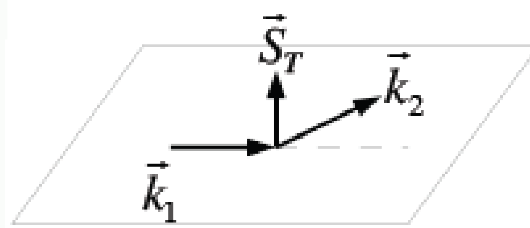


$e + {}^3He \to A + X$

$A = e',\ \pi^{+/-}$ or p

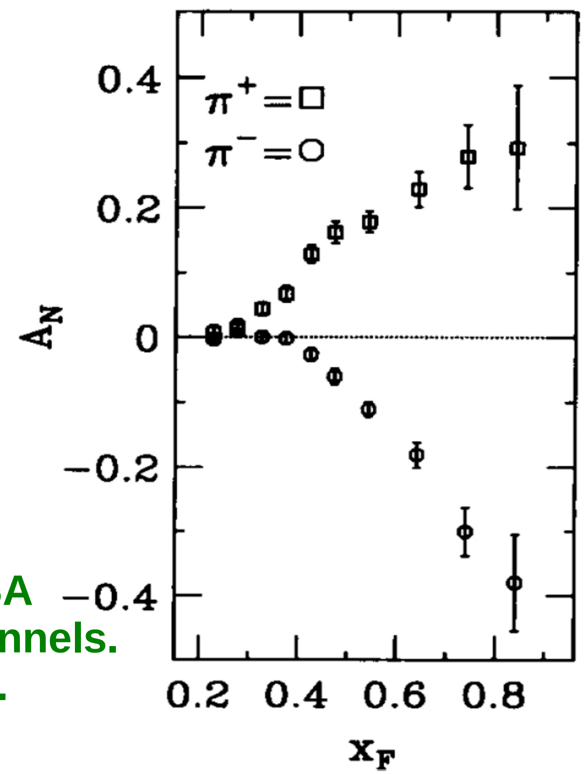


$$(\vec{k}_1 \times \vec{k}_2) \bullet \vec{S}_T = 0$$



$$(\vec{k}_1 \times \vec{k}_2) \bullet \vec{S}_T \neq 0$$

Recall in $pp^{\uparrow} \to \pi X$
FNAL-E704: √s =20 GeV.
PLB 264 (1991) 462.

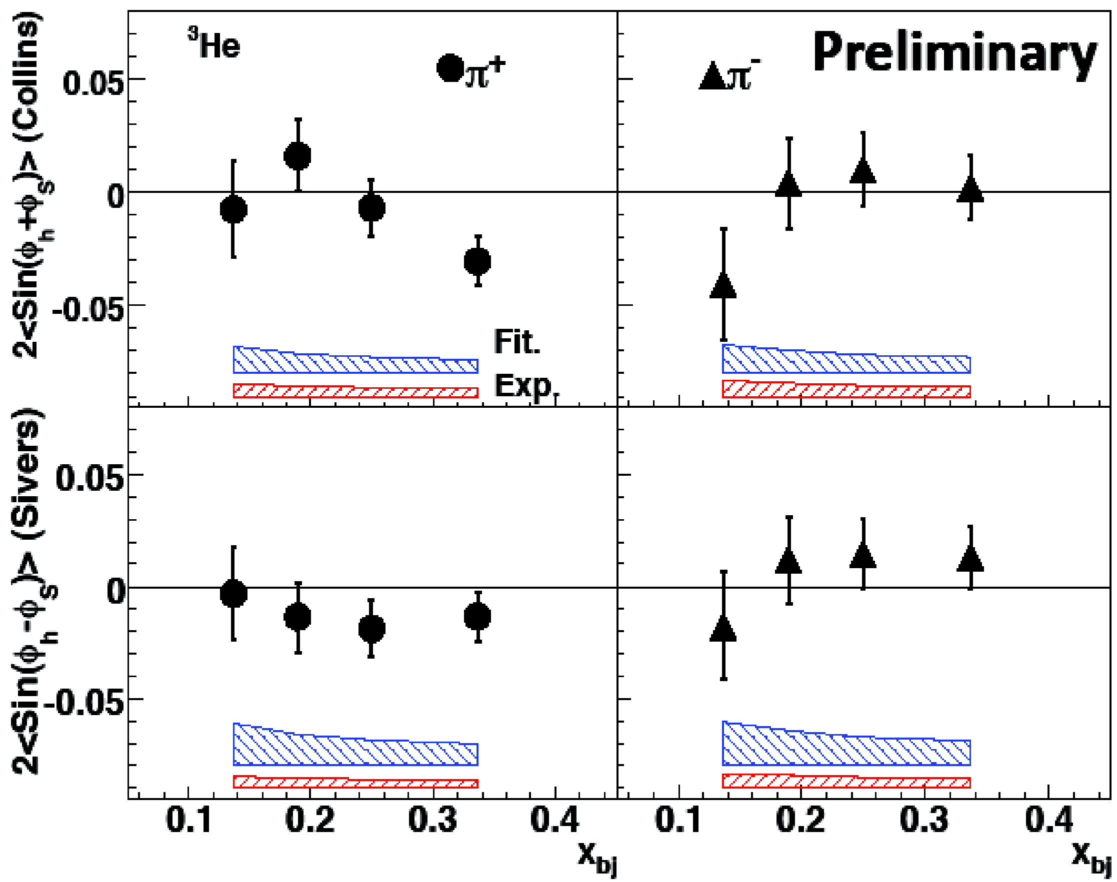


Clear non-zero target SSA observed in witness channels. False asymmetry < 0.1%.

X International Workshop on

^{3}He A_{UT} Results

- Consistent with zero for π^-
- Favors negative amplitude for π^+ Sivers asymmetry



Extraction of neutron results from ^{3}He:

$$A_{^3\mathrm{He}}^{C/S} = P_n \cdot (1 - f_p) \cdot A_n^{C/S} + P_p f_p \cdot A_p^{C/S}$$

$$P_n = 0.86^{+0.036}_{-0.02} \quad and \; P_p = -0.028^{+0.009}_{-0.004}$$

$$f_p = \frac{2\sigma_p}{\sigma_{^3\mathrm{He}}}$$

Cross-section ratio is determined using H_2 and ^{3}He reference cell runs

Neutron A_{UT} Results

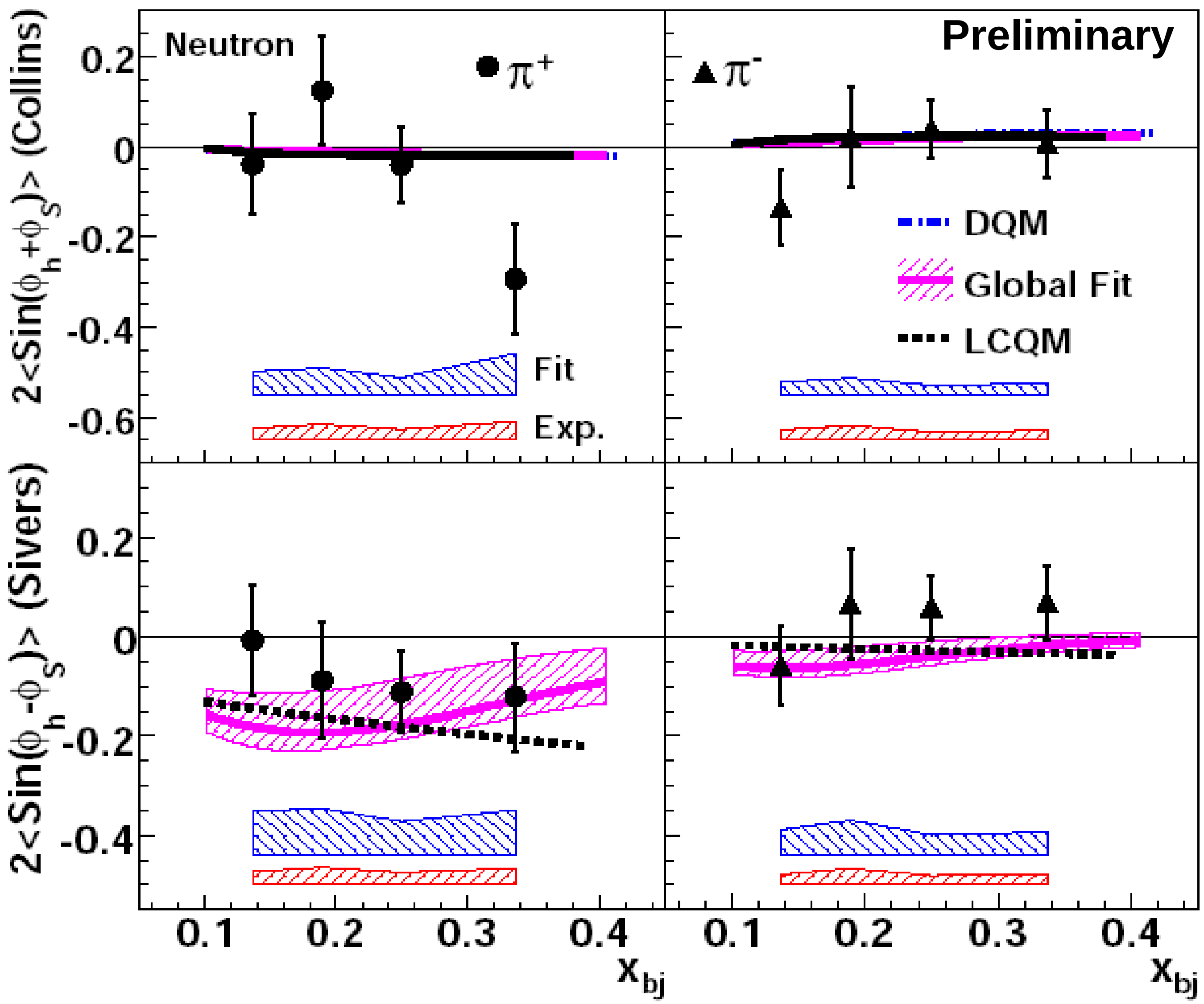
$\langle Q^2 \rangle \sim 2.0\ GeV^2$
$\langle W \rangle \sim 2.8\ GeV^2$
$\langle z \rangle \sim 0.5$

Collins Moments

- Consistent with zero for π^-
- Consistent with zero for π^+ except at x ~ 0.34

Sivers Moments

- Sensitive to the d-quark
- Consistent with zero for π^-
- Favors negative values for π^+



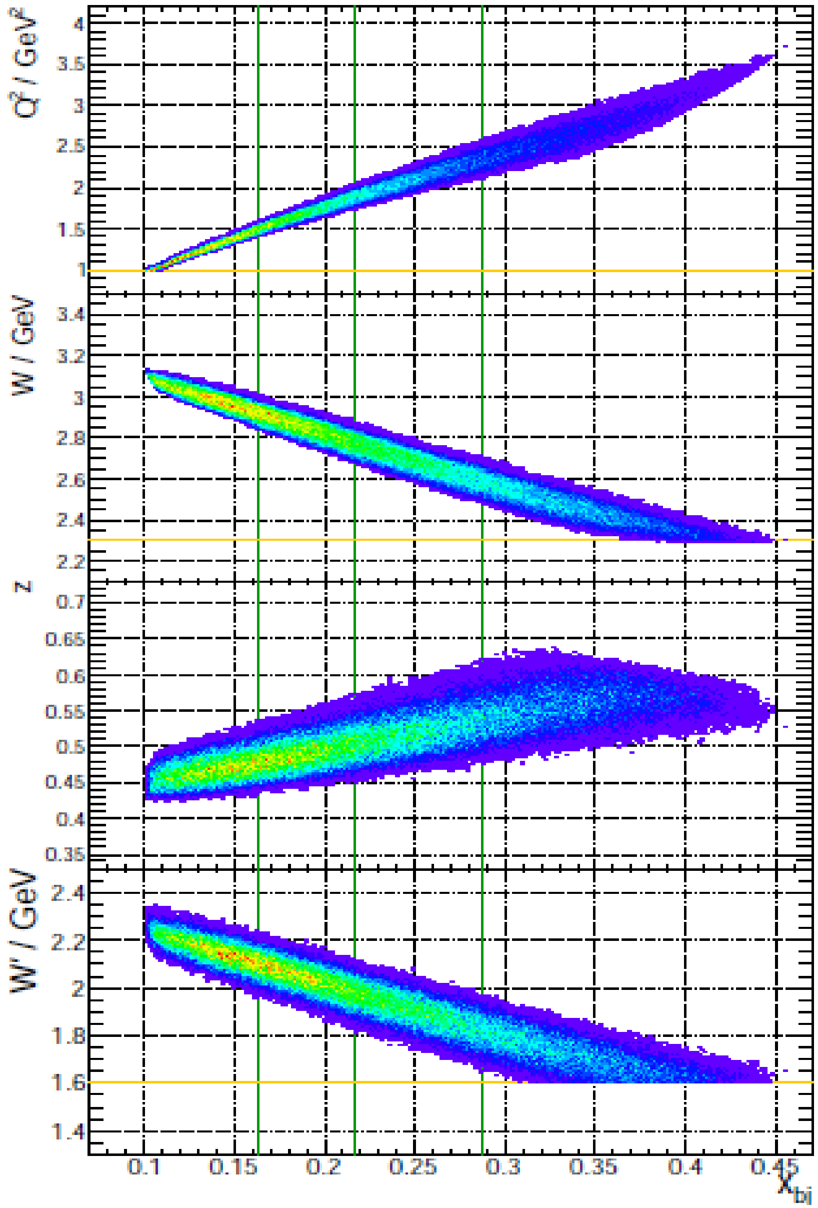
Blue: Fit uncertainties due to neglecting other angular terms

Summary

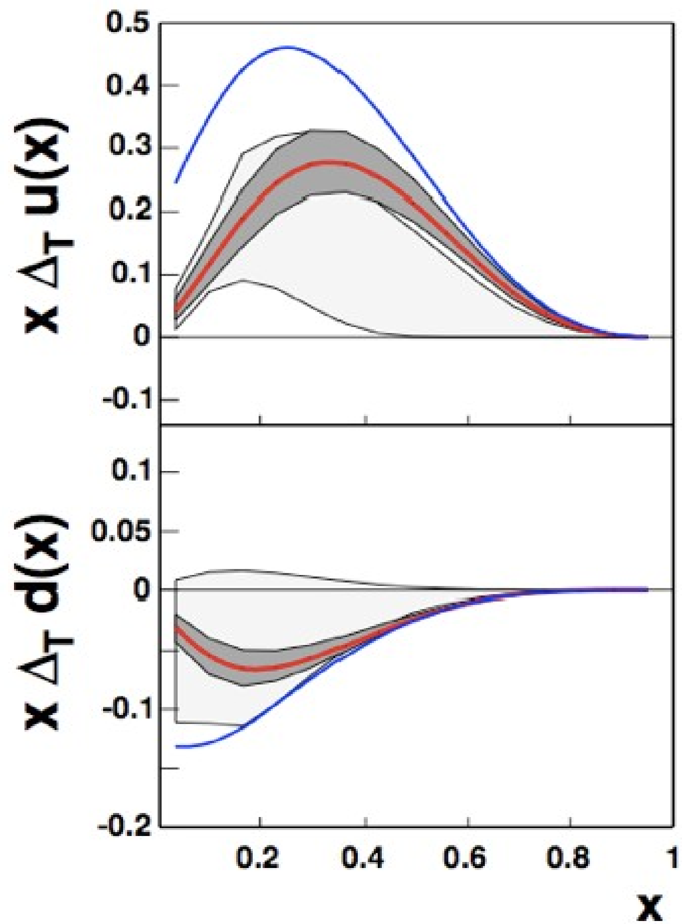
- First measurement of Collins and Sivers moments (A_{UT}) on ^{3}He target
- A_{UT} results on neutron:
  - Collins: π^- and π^+ asymmetries are consistent with zero except at x~0.34 for π^+
  - Sivers: π^- is consistent with zero but π^+ favor negative values
- Along with existing proton and deuteron data, neutron results will help in constraining d-quark Sivers function using global fits.
- Results will be soon out for publication
- JLab 12GeV Transversity experiment using a Solenoid detector (SoLID) will improve the kinematical coverage in x, Q^2, P_T and z and achieve much higher precision

Backup Slides

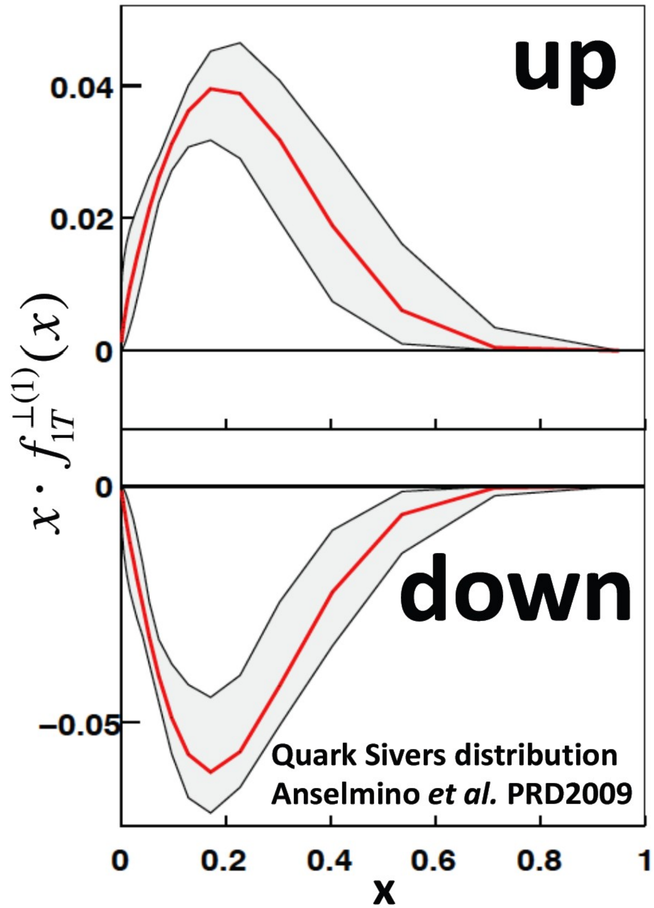
Kinematics Correlation



Transversity



Sivers



$$A_{UT}^{Collins} = \frac{(1-y)}{(1-y+y^2/2)} \frac{\sum_q e_q^2 h_1^q(x) H_1^{\perp(1)q}(z)}{\sum_q e_q^2 f_1^q(x) D_1^q(z)}$$

D_{nn} = 0.2 – 0.4 (in Hall-A E06-010 Expt.)

$$A_{UT}^{Sivers} = \frac{\sum_q e_q^2 f_{1T}^{\perp(1)q}(x) D_1^q(z)}{\sum_q e_q^2 f_1^q(x) D_1^q(z)}$$